Moving Beyond the Finite Elements: A Comparison between Finite Element Methods and Meshless Methods for Modeling Honeycomb Materials and Simulating Side Impact Moving Deformable Barriers (MDBs)

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ABSTRACT

Movable Deformable Barriers (MDBs) are used in surrogate tests to represent the behavior of an average midsize vehicle. The main difficulty in MDB modeling is the prediction of frontal energy absorbing barrier, where honeycomb materials are used and usually expected to simulate complex failure modes. In side impact tests, the severe shear deformation of the honeycomb material, full densification of barrier edge, rupture of aluminum cover sheets, and tearing of honeycomb blocks are often observed. This complex pattern of honeycomb material failure mode makes it difficult to predict. Numerical instabilities, such as negative volume, severe hourglassing, and inaccurate predictions are often experienced.

In this study, National Highway Transportation Safety Administration (NHTSA) side impact MDB is modeled by using a 3D non-linear explicit dynamics numerical solver, LS-DYNA. As a conventional modeling technique, both barriers are first modeled by using Lagrangian solid hexahedron finite elements (FEs). Mat-26 (*MAT_HONEYCOMB) is used as a constitutive model for the barrier construction. By using this Lagrangian model as a reference point, Eulerian and Arbitrary-Lagrangian Eulerian (ALE) models of the MDBs are also created. However, when the distortions become very severe, especially Lagrangian FE algorithms are not always adequate. Honeycomb material behavior is found to behave unstable in this type of impact problems. More recently meshless methods (or particle methods) have been developed and applied to solid mechanics problems since they can efficiently be used to represent severe distortions. In this study, Element Free Galarkin (EFG) model of the MDB is also created. Each MDB model is compared to a full scale crash test against a load cell wall. Accelerometer responses from the simulations are compared to the measured values from the test. Computational costs of the systems are also compared to provide a foresight for the usage of the meshless methods in transportation safety field related research.

INTRODUCTION

The Federal Motor Vehicle Safety Standards (FMVSS) Section 214, which is published by NHTSA covers the requirements of passenger vehicles in terms of side impact protection by using a MDB impact test. FMVSS-214 is used to evaluate the performance of passenger vehicles in car-to-car side crashes [1]. The standard mimics a car-to car side impact where the struck car is stationary and the striking car, represented by a moving deformable barrier.

The test configuration as specified by NHTSA is shown in Figure 1 [2]. In this setup, MDB is shown impacting the side of a stationary vehicle at 54 km/h (33.5 mph). The MDB is towed at a crabbed angle of 27^0 to its longitudinal axis. This configuration is intended to simulate a striking generic vehicle moving at 48.4 km/h (30 mph), perpendicular to the side of the struck vehicle traveling at 24.2 km/h (15 mph). The crabbed angle configuration allows the simulation of a two-vehicle side impact, both in motion condition, using a simplified test method where only one vehicle is in motion. Figure 2 illustrates the deformable part of the MDB. This part is mainly designed by using Aluminum honeycomb structures.

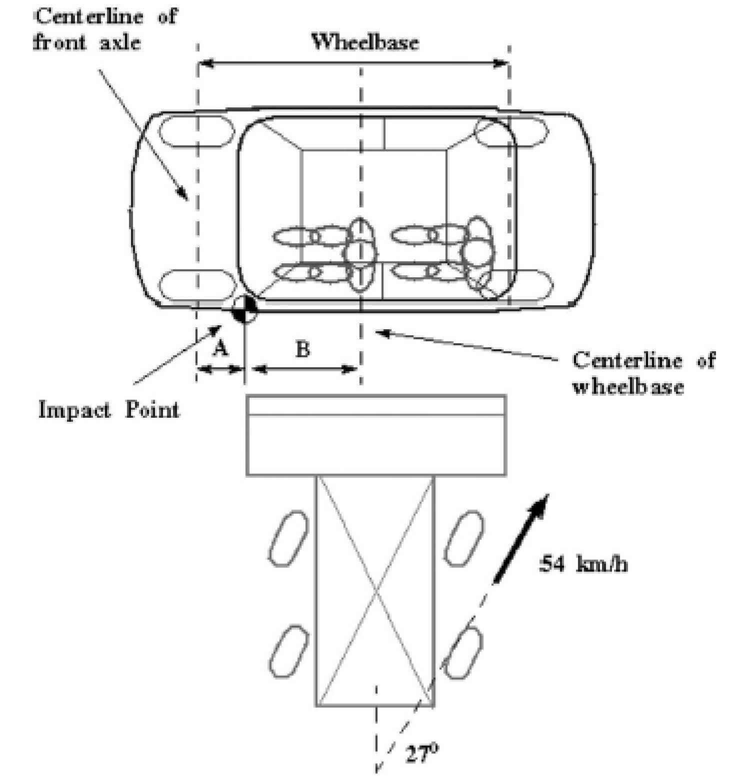


Figure 1. NHTSA FMVSS-214 MDB test setup.

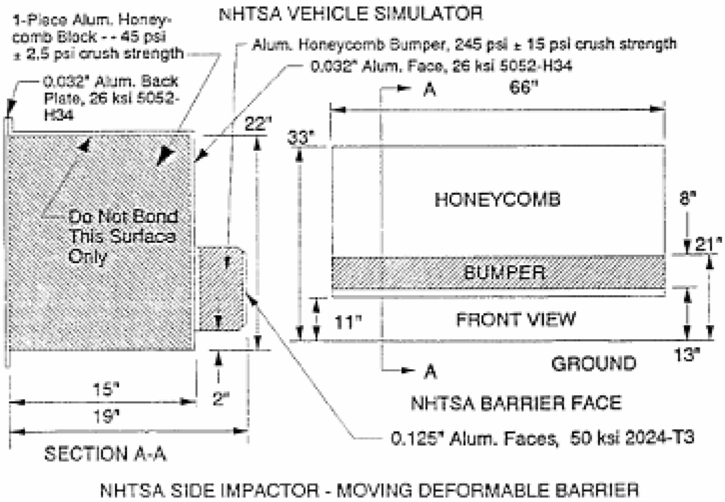


Figure 2. NHTSA FMVSS-214 MDB frontal deformable section.

In this study, a rigid wall impact scenario is considered to be able to compare the differences of the numerical models for a controlled environment which will be independent of the vehicle type. Different element formulations and numerical schemes are compared to each other to see the effect and feasibility of the meshless algorithms.

Experimental Study

As part of the validation process, simulations with the various element formulations are compared to available full-scale test. Test number V1068 conducted by NHTSA at the Vehicle Research and Test Center is used in this study [3]. In this test, the MDB was towed into a fixed load cell barrier at a perpendicular angle. The impact speed of the test was 40.2 km/h (25 mph), with the MDB crabbed at a 26^0 angle. The fixed load cell barrier was composed of 36 loads cells in a 4 rows x 9 columns configuration that is shown in Figure 3. The barrier was at 66 mm (2.6 in.) from the ground.

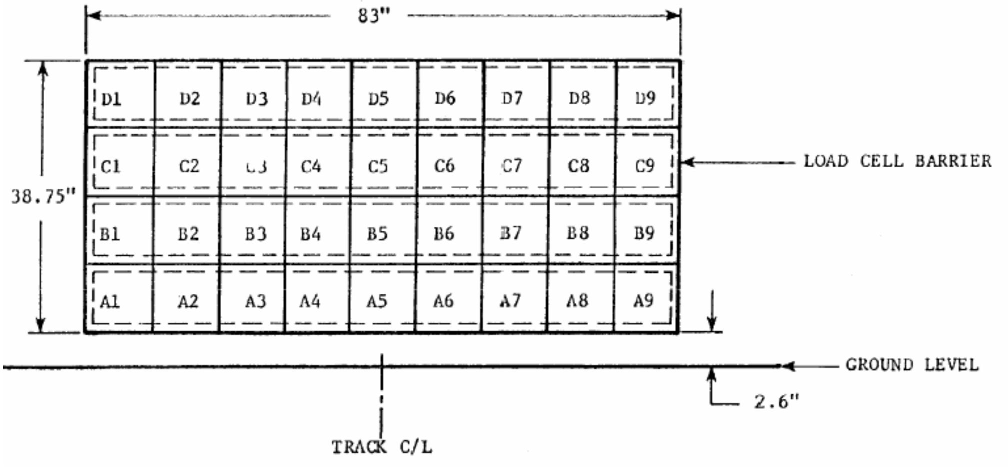


Figure 3. Barrier load cell configuration.

Figure 4 shows the overall right side view of the test setup. The rigid wall is instrumented with load cells that measure the force imparts to a specific area of the wall. The vehicle is also instrumented with accelerometers.

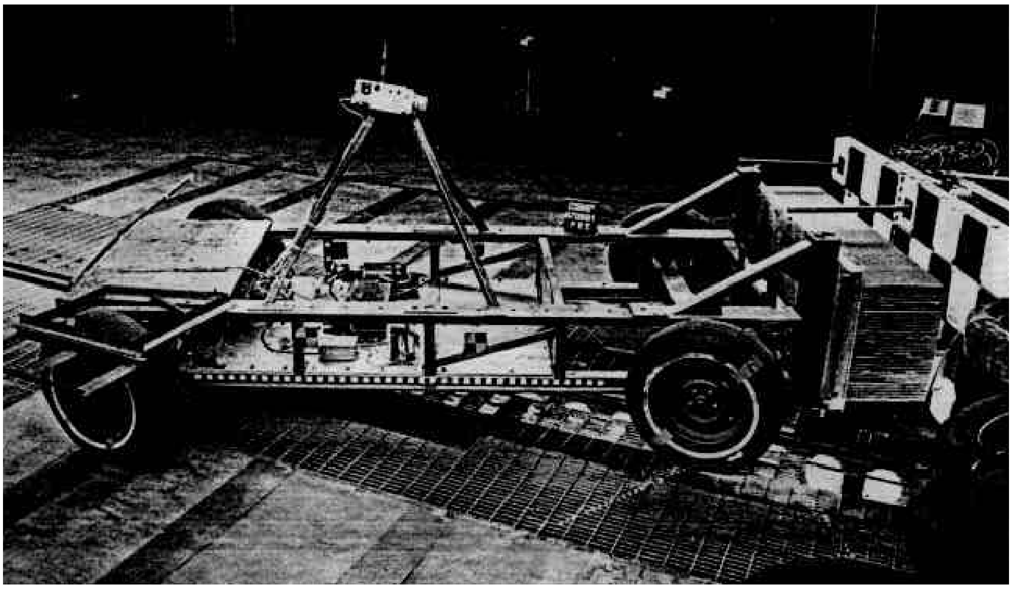


Figure 4. Pre-test right overall view.

Numerical Study

In this study, an already validated FE model of the FMVSS-214 MDB is used that is developed by FHWA/NHTSA National Crash Analysis Center (NCAC) based on an earlier version that was originally developed by NHTSA [3].

Finite Element Model

Figure 5 represents the finite element model of the MDB that is developed by NCAC. Lagrangian hexahedron elements are used with honeycomb materials for the energy absorbing frontal barrier face as shown in Figure 6. Test V1068 setup and load cell rigid barrier are also represented in Figure 7.

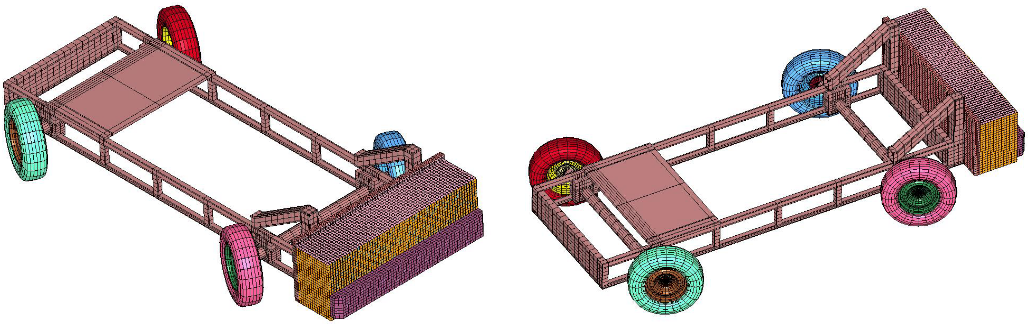


Figure 5. NCAC MDB finite element model.

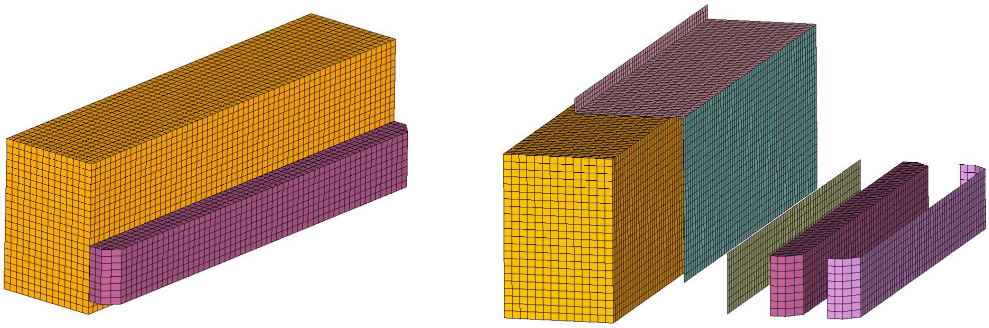


Figure 6. Frontal face finite element model.

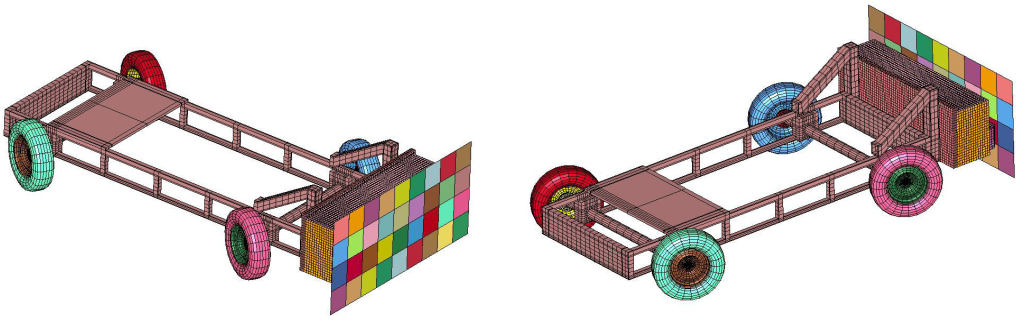


Figure 7. Test setup.

The original Lagrangian single point integration MDB frontal face elements are also modeled by using fully integrated Lagrangian, Arbitrary-Lagrangian Eulerian (ALE), Eulerian and Element Free Galerkin (EFG) formulations and compared with the experimental results.

Element Free Galerkin (EFG) Model

Mesh-free methods, which construct the approximation entirely in term of nodes, permit reduced restriction in the discretization of the problem domain and are less susceptible to distortion difficulties than finite elements. For a variety of engineering problems with extremely large deformation, moving boundaries or discontinuities, mesh-free methods are very attractive [4, 5]. These methods can be easily used to solve transportation safety problems especially on the crashworthiness side. Structures that are subjected to extreme distortion are good candidates to be modeled by using the power of mesh-free methods. However, these methods are usually at least two times expensive than regular Lagrangian methods. So, it is important to create optimized-coupled FE and mesh-free models to satisfy the overall computational cost. Usually, modeling the parts that are subjected to severe deformation with EFG method is a general approach.

In this study, a coupled finite element and mesh-free model for MDB is developed. This model is developed to minimize the mesh distortion problems encountered in the finite element analysis and to reduce the computational cost associated with the mesh-free computation. Coupling between the mesh-free and finite element parts are established through contact-impact algorithms. Figure 8 shows the front face honeycomb materials that are modeled with EFG formulation.

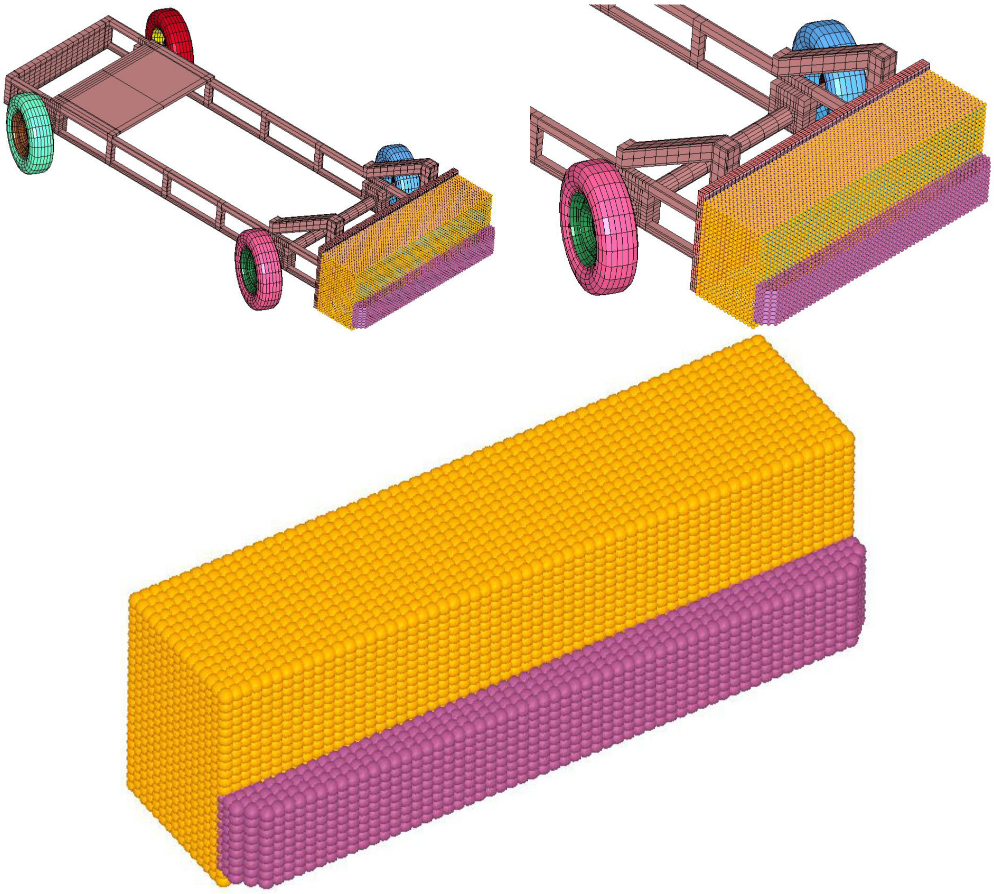


Figure 8. Coupled EFG-FE MDB front face model.

Constitutive Model

The most important part of modeling a MDB is the honeycomb material properties that are used for the energy absorbing frontal face. *MAT_HONEYCOMB material definition card is used for these parts [2, 6, and 7]. Table 1 shows the material model parameters for both 245 and 45 psi crush strength.

*MAT_HONEYCOMB	245 psi Honeycomb	45 psi Honeycomb
Density (t/mm3)	8.5E-11	2.62E-11
Young's Modulus (Mpa)	68950	68950
Poisson's Ratio	0.33	0.33
Yield Stress (MPa)	160	160
Relative Volume (Compacted)	0.031	0.009
Elastic Modulus Eaau (Mpa)	1020	172
Elastic Modulus Ebbu (Mpa)	340	57.2

Elastic Modulus Eccu (Mpa)	340	57.2
Shear Modulus Gabu (Mpa)	434	145
Shear Modulus Gbcu (Mpa)	214	75
Shear Modulus Gcau (Mpa)	434	145

Results

Figure 9 illustrates a comparison between the resultant acceleration obtained from an accelerometer that is located at the center of gravity (CG) of the MDB and corresponding numerical findings at the same location for the first 100 msec.

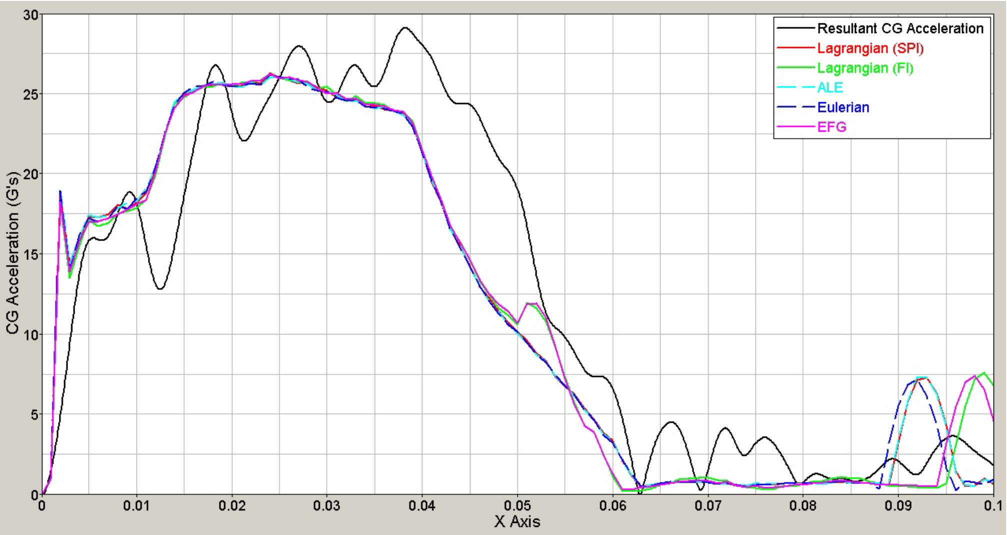
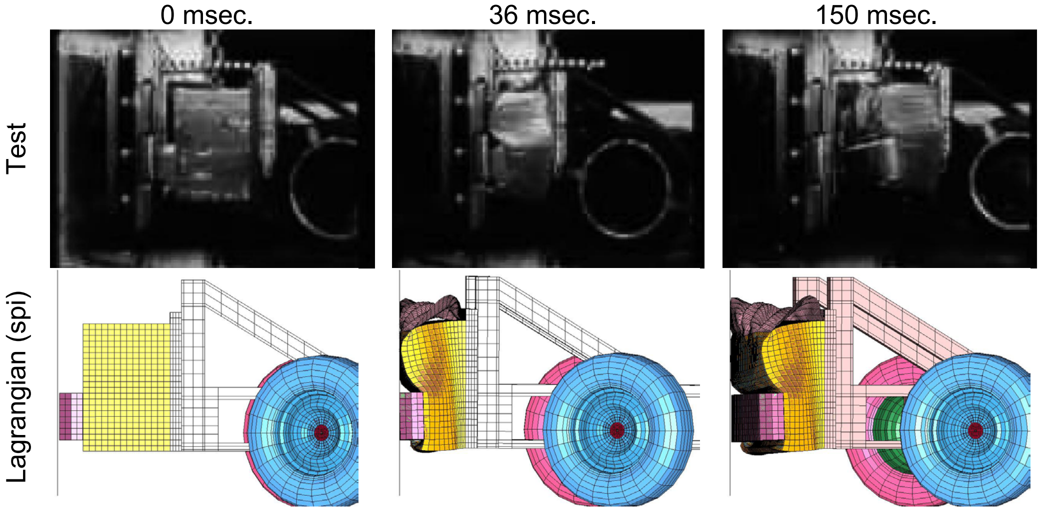


Figure 9. Comparison of resultant acceleration at CG.

The general deformation of the barrier in the simulation is compared visually to the images captured from the full-scale crash test with the high-speed cameras. Figures 10 and 11 show side and top views of the MDB at the initial state, 36 msec., and 150 msec. The results are given for the single point integration (spi) Lagrangian, fully integrated (fi) Lagrangian, ALE, Eulerian and EFG models.



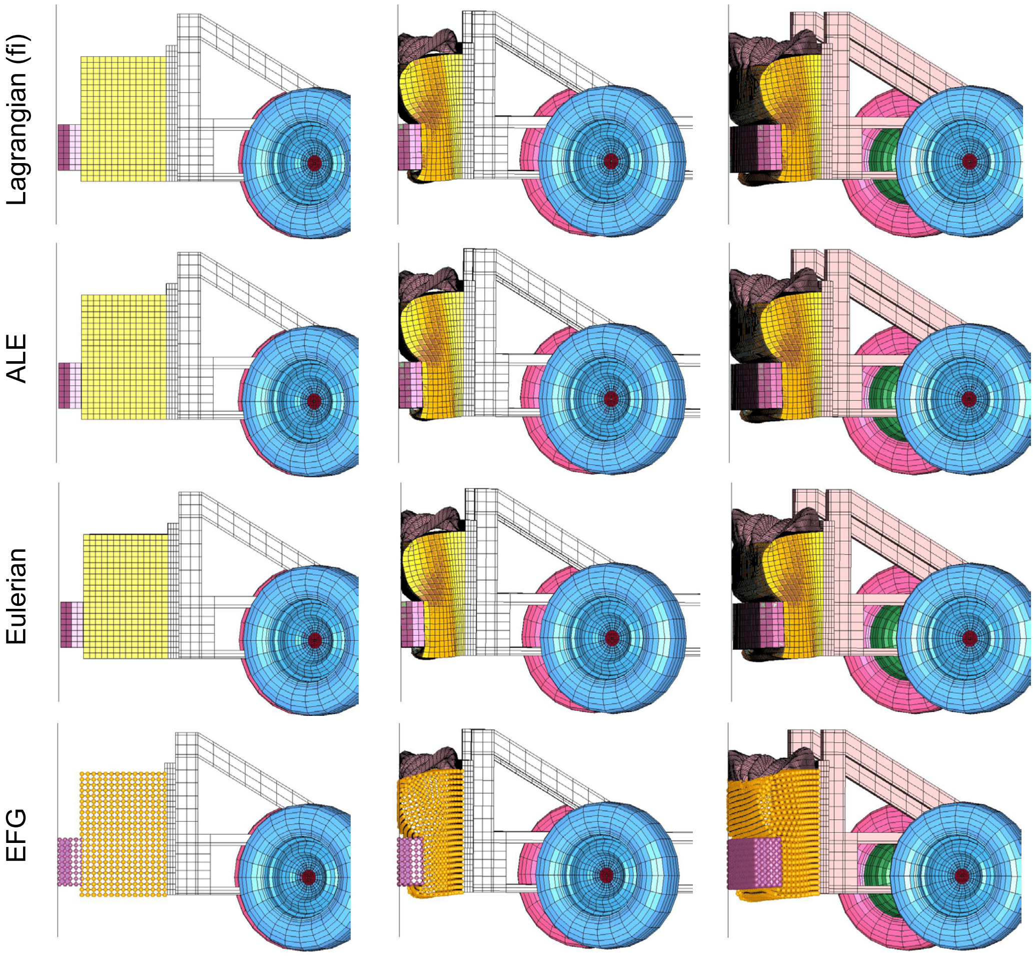
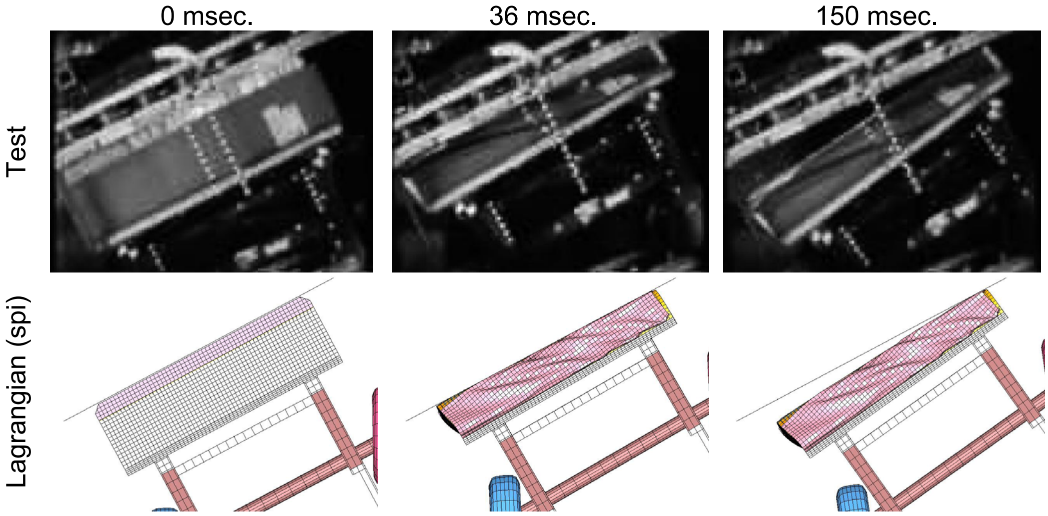


Figure 10. Side view comparison of MDB crash test results.



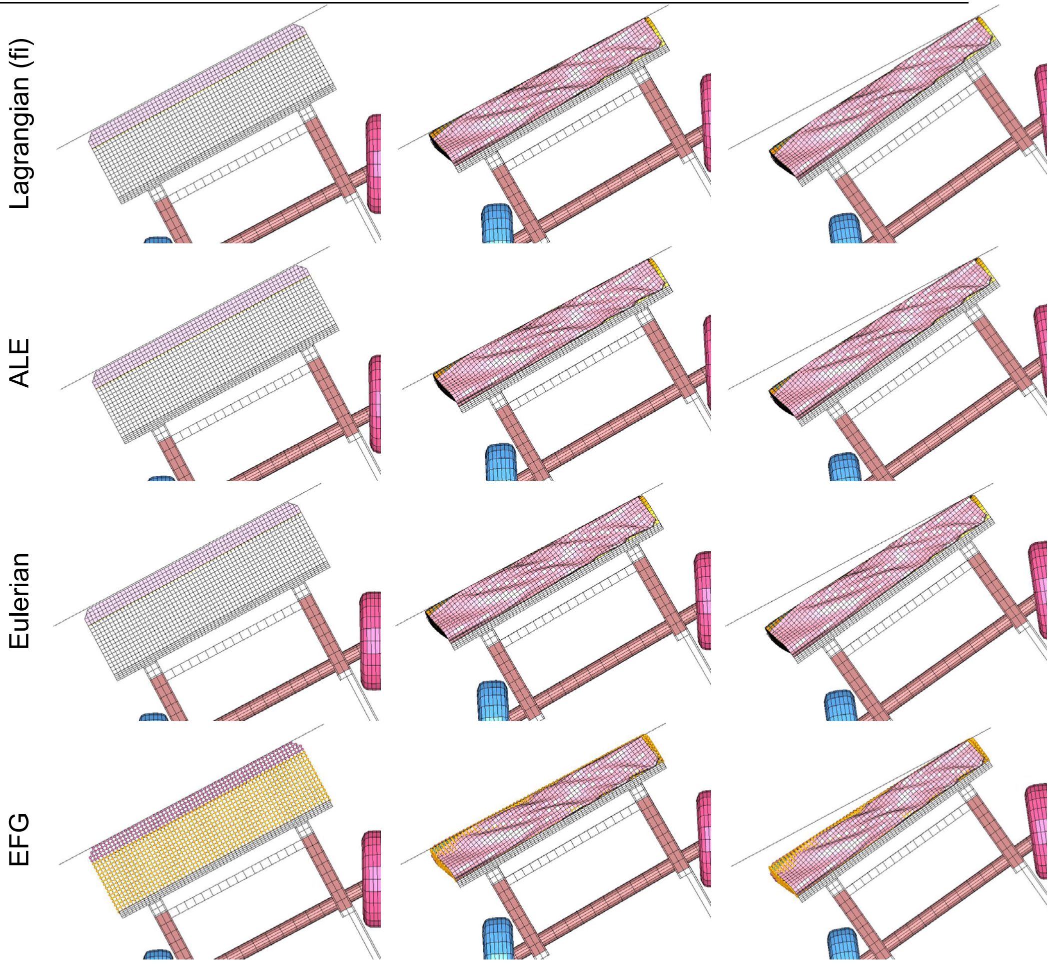


Figure 11. Top view comparison of MDB crash test results.

Figure 12 illustrates the computational cost of each numerical scheme used for modeling MDB. The simulations are performed on a SGI Origin 3800 platform with 4 CPU's.

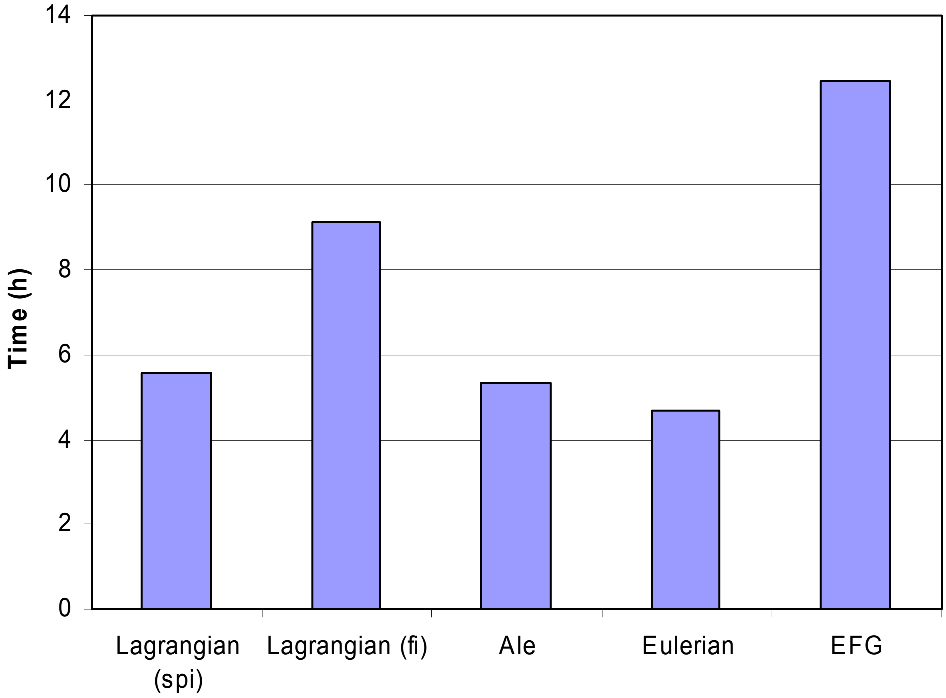


Figure 12. Computational cost of each numerical scheme.

Summary and Conclusions

Single point integration and fully integrated Lagrangian, ALE, Eulerian and EFG formulations are used to create a FMVSS-214 MDB model.

The acceleration readings from the crash test are compared with the simulation results and are found to be in reasonably good agreement.

Minor differences are found between the numerical schemes for this case study. The reason for that may be explained by the relatively low level of energy that is absorbed during the crash test at 25 mph. EFG formulation is expected to be more beneficial for higher energy levels. However, hybrid FE-EFG models are found to be still cost effective and feasible for solving and simulating transportation safety problems.

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